



Indian Journal of Pure & Applied Physics  
Vol. 58, August 2020, pp. 599-604



# Novel Current-Mode Universal Filter using single FTFNTA

Ravendra Singh & Dinesh Prasad\*

Department of Electronics & Communication Engineering, Faculty of Engineering & Technology, Jamia Millia Islamia,  
New Delhi, 110 025, India

Received 23 October 2019; accepted 6 July 2020

In this paper, a novel universal filter using single Four Terminal Floating Nullor Transconductance Amplifier (FTFNTA), two capacitors and one/two resistor has been proposed. Sensitivity of pole frequency ( $\omega_0$ ) and quality factor ( $Q_0$ ) is analysed. Workability of proposed filter has been demonstrated by PSPICE simulations in 0.18 $\mu$ m TSMC CMOS technology.

**Keywords:** FTFNTA, Biquad Universal Filter, Current Mode, FTFN.

## 1 Introduction

Filters are the essential modules for signal processing applications *i.e.* speech processing, data acquisition, mobile switching centres (MSCs), phase shifting<sup>1-2</sup>, etc. Behaviourally, analog filters are grouped by their mode of operation such as current-mode (CM) or voltage-mode (VM) filter. They are also classified according to their input (i/p) output (o/p) combination such as single i/p multiple o/p (SIMO) and multiple i/p single o/p (MISO) filter. However, the CM filters are more popular than VM filters<sup>3</sup> due to its advantage over VM. Therefore, various CM active filters have been proposed and studied in the literature.

In this manuscript, an advance variant of Four Terminal Floating Nullor (FTFN) *i.e.* Four Terminal Floating Nullor Transconductance Amplifier (FTFNTA) is used as an active building block. FTFN is a protean active building block because it incorporates the VM and CM capabilities. There are various FTFN based filters were developed in<sup>5-13</sup>. These structures are able to design all filter functions for different input-output combinations. Previously reported filters based on FTFN are suffering from various limitations such the use of floating components, the requirement of an auxiliary circuit, need of too many active and /or passive components and pole frequency ( $\omega_0$ ) and quality factor ( $Q_0$ ) dependency.

In this manuscript, a MISO CM universal filter using a single FTFNTA is proposed. For different input combinations, different filters will be realized

*i.e.* low-pass (LPF), band-pass (BPF) and high-pass (HPF) filter, one at a time. The operation of the proposed design is validated by PSPICE simulation using 0.18  $\mu$ m technology.

## 2 Basic Concept of the FTFNTA

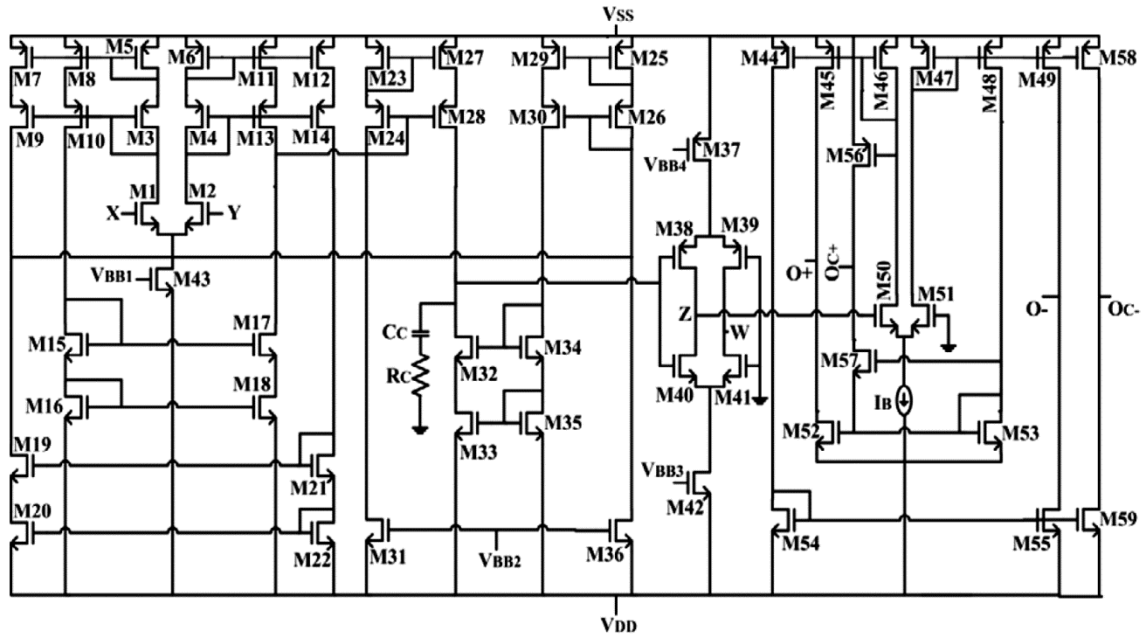
The FTFNTA, a recently introduced CM active block, is a combination of FTFN at i/p stage accompanied with OTA at o/p stage<sup>4</sup>. The CMOS realization of the FTFNTA is shown in Fig. 1. The value of the supply and bias voltage is  $V_{DD} = 1.65V$ ,  $V_{SS} = -1.65V$ ,  $V_{BB1} = V_{BB2} = -1V$ ,  $V_{BB3} = -0.8V$  and  $V_{BB4} = 0.5V$ . The value of bias current  $I_B$  is chosen as 600 $\mu$ A. The aspect ratios of the transistors PMOS and NMOS of the FTFNTA are listed in Table 1. The circuit schematic of an FTFNTA is shown in Fig. 2.

It is a six-port device. Amongst the available ports, the X and Y are I/P ports and Z, W, O+ and O- are the O/P ports. Port W evinces low impedance while all other port has high impedance. Both X and Y ports are buffered, *i.e.* no current will flow through these ports. The output current  $I_{O+}$  and  $I_{O-}$  has a transconductance gain incorporated with it. The characteristic equation of FTFNTA is stated in Eq. (1).

$$\begin{bmatrix} I_X \\ I_Y \\ V_X \\ I_Z \\ I_{O+} \\ I_{O-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \alpha & 0 & 0 \\ 0 & -\beta & 0 \\ 0 & 0 & \gamma g_m \\ 0 & 0 & -\gamma g_m \end{bmatrix} \begin{bmatrix} V_Y \\ I_W \\ V_Z \end{bmatrix} \quad \dots(1)$$

$$g_m = \sqrt{I_B \mu_n C_{ox} \left( \frac{W}{L} \right)} \quad \dots(2)$$

\*Corresponding author: (Email -dprasad@jmi.ac.in)

Fig. 1 — CMOS Realization of the FTFNTA, as presented in<sup>4</sup>Table 1 — Aspect ratios of the transistors of the FTFNTA<sup>4</sup>

CMOS Transistors	L (μm)	W (μm)
M1-M2	0.6	5
M3-M6	0.6	1.2
M7-M14, M42	0.6	50
M15-M22	0.6	212
M23-M26	0.7	4
M27-M30	0.7	20
M31, M36	0.7	3
M32-M35	0.7	7
M37	0.7	78
M38-M39	0.7	150
M40-M41	0.7	120
M43	0.6	18
M44, M47	0.18	1.44
M45-M46, M56	0.18	0.72
M48-M49, M52-M53, M57-M58	0.18	0.54
M50-M51	0.18	5
M54-M55, M59	0.18	1.44

Where,

$I_B$  - Bias current

$\mu_n$  - Mobility of free charge carrier present in the channel

$C_{ox}$  - Gate-oxide layer capacitance

W - Channel width

L - Channel length.

$\alpha$  is the voltage transfer gain,  $\beta$  is the current transfer gain and  $\gamma$  is the transconductance transfer accuracy. Ideally, the value of  $\alpha$ ,  $\beta$  and  $\gamma$  is unity.

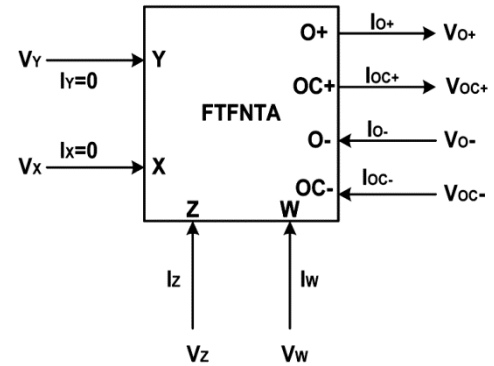


Fig. 2 — Circuit Schematic of a FTFNTA

These  $\alpha$ ,  $\beta$  and  $\gamma$  are accountable for the non-ideality of FTFNTA.

### 3 Proposed Circuit Descriptions and Analysis

Proposed MISO Biquad Filter consists of only one FTFNTA as an active element. The general circuit of TISO is shown in Fig. 3.

Typical nodal analysis of the structure in Fig. 3 relents the general transfer function as given below in Eq. (3). Here  $I_1$ ,  $I_2$ , and  $I_3$  are the current i/p signals and  $I_{out}$  is the current o/p signal.  $Y_1$ - $Y_6$  are admittance parameters, either resistance or capacitor.

From Eq. (3), it is clear that the most suitable of i/p signals and admittance parameters  $Y_1$ - $Y_6$ , different filtering functions can be perceived across o/p terminal ( $O_{C+}$ ) as depicted in Table 2.

$$I_{out} = \frac{g_m(Y_1+Y_2)(Y_5+Y_6)I_1 - Ag_mY_5I_2 + g_mY_5(Y_1+Y_2)I_3}{g_m(Y_1+Y_2)(Y_5+Y_6) + Y_5(Y_1+Y_2)(Y_3+Y_2) + AY_5(g_m+Y_2)} \quad \dots(3)$$

Where “A” is constant given as:

$$A = \frac{(Y_4 + Y_5)(Y_5 + Y_6) - Y_5(Y_5 + Y_2)}{Y_5} \quad \dots(4)$$

### 3.1 Low pass filter

After applying the conditions mentioned in Table 2 the modified structure of LPF is shown in Fig. 4 and its transfer function is given by

$$\frac{I_{out}}{I_{LP}} = \frac{I_{out}}{I_3} = \frac{Y_1 Y_5}{Y_4 Y_6 + Y_4 Y_5 + Y_5 Y_6 + Y_1 Y_6 + Y_1 Y_5} \quad \dots(5)$$

For  $Y_1 = 1/R_1$ ,  $Y_5 = 1/R_5$ ,  $Y_4 = sC_4$ ,  $Y_6 = sC_6$

$$\frac{I_{out}}{I_{LP}} = \frac{I_{out}}{I_3} = \frac{1/R_1 R_5 C_4 C_6}{s^2 + s\left(\frac{1}{C_6 R_5} + \frac{1}{C_4 R_5} + \frac{1}{C_6 R_1}\right) + \frac{1}{R_1 R_5 C_4 C_6}} \quad \dots(6)$$

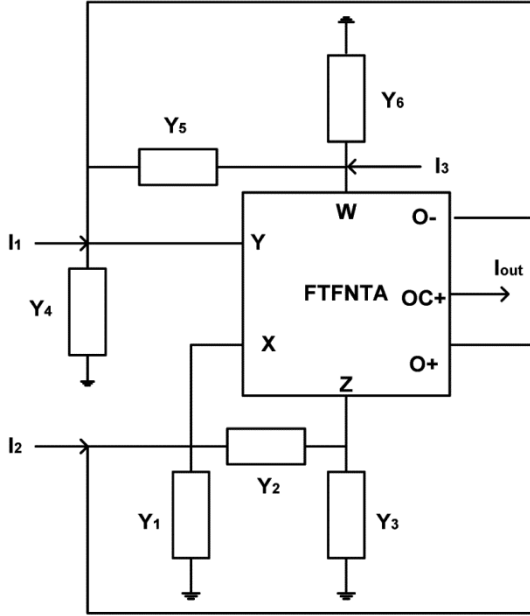


Fig. 3 — Proposed MISO Biquad filter

If  $R_1 = R_5 = R$  and  $C_4 = C_6 = C$  then

$$\frac{I_{out}}{I_{LP}} = \frac{I_{out}}{I_3} = \frac{1/R^2 C^2}{s^2 + 3s\frac{1}{RC} + \frac{1}{R^2 C^2}} \quad \dots(7)$$

### 3.2 High pass filter

After applying the conditions mentioned in Table 2, the modified structure for designing of HPF is shown in Fig. 5 and its transfer function is given by

$$\frac{I_{out}}{I_{HP}} = \frac{I_{out}}{I_2} = \frac{g_m Y_5 (Y_2 - Y_6)}{Y_2 Y_6 Y_5 + g_m Y_6 (Y_2 + Y_5)} \quad \dots(8)$$

For  $Y_6 = 1/R_2$ ,  $Y_5 = sC_5$ ,  $Y_2 = sC_2 + 1/R_2$

$$\frac{I_{out}}{I_{HP}} = \frac{I_{out}}{I_2} = \frac{g_m R_2 s^2}{s^2 + s\left(\frac{1}{C_2 R_2} + \frac{g_m}{C_5} + \frac{g_m}{C_2}\right) + \frac{g_m}{R_2 C_2 C_5}} \quad \dots(9)$$

If  $R_2 = R$  and  $C_2 = C_5 = C$  then

$$\frac{I_{out}}{I_{HP}} = \frac{I_{out}}{I_2} = \frac{g_m R s^2}{s^2 + s\left(\frac{1}{RC} + \frac{2g_m}{C}\right) + \frac{g_m}{RC^2}} \quad \dots(10)$$

### 3.3 Band pass filter

After applying the conditions mentioned in Table 2 the modified structure for designing of BPF is shown in Fig. 6 and its transfer function is given by

$$\frac{I_{out}}{I_{BP}} = \frac{I_{out}}{I_1} = \frac{g_m Y_2}{Y_2 Y_3 + g_m Y_4 + Y_2 Y_4} \quad \dots(11)$$

For  $Y_4 = 1/R_4$ ,  $Y_2 = sC_2$ ,  $Y_3 = sC_3$

$$\frac{I_{out}}{I_{BP}} = \frac{I_{out}}{I_1} = \frac{s g_m / C_3}{s^2 + s\left(\frac{1}{C_3 R_4} + \frac{g_m}{R_4 C_2 C_3}\right)} \quad \dots(12)$$

If  $R_4 = R$  and  $C_2 = C_3 = C$  then

$$\frac{I_{out}}{I_{BP}} = \frac{I_{out}}{I_1} = \frac{s g_m / C}{s^2 + s\left(\frac{1}{RC} + \frac{g_m}{RC^2}\right)} \quad \dots(13)$$

It is observed from Eq. (7), (10) and (13) that LP, BP, and HP filters are designed from the proposed structure. Further, the parameters like  $\omega_0$ ,

Table 2 — Functionality of the proposed filter

S. No	Parameter	Input Current	Type of the filter	Transfer Function	$\omega_0$	$Q_0$	BW
1.	$Y_2 = Y_3 = 0$ $Y_1 = 1/R_1$ , $Y_5 = 1/R_5$ $Y_4 = sC_4$ , $Y_6 = sC_6$	$I_1 = 0$ $I_2 = 0$ $I_3 = I_{LP}$	LPF	$I_{out}/I_{LP}$	$\sqrt{\frac{1}{R_1 R_5 C_4 C_6}}$	$\frac{\sqrt{R_1 R_5 C_4 C_6}}{C_4 R_1 + C_6 R_1 + C_4 R_5}$	$\frac{1}{\frac{C_6 R_5}{1} + \frac{C_4 R_5}{1} + \frac{C_6 R_1}{1}}$
2.	$Y_1 = Y_3 = Y_4 = 0$ $Y_6 = 1/R_2$ , $Y_5 = sC_5$ $Y_2 = sC_2 + 1/R_2$	$I_1 = 0$ $I_2 = I_{HP}$ $I_3 = 0$	HPF	$I_{out}/I_{HP}$	$\sqrt{\frac{g_m}{R_2 C_2 C_5}}$	$\frac{\sqrt{g_m R_2 C_2 C_5}}{C_5 + g_m R_2 C_2 + g_m R_2 C_5}$	$\frac{1}{\frac{C_2 R_2}{C_5} + \frac{g_m}{C_5} + \frac{g_m}{C_2}}$
3.	$Y_1 = Y_6 = 0$ , $R_5 = 0$ $Y_4 = 1/R_4$ , $Y_2 = sC_2$ $Y_3 = sC_3$	$I_1 = I_{BP}$ $I_2 = 0$ $I_3 = 0$	BPF	$I_{out}/I_{BP}$	$\sqrt{\frac{g_m}{R_4 C_2 C_3}}$	$\sqrt{\frac{g_m R_4 C_3}{C_2}}$	$\frac{1}{C_3 R_4}$

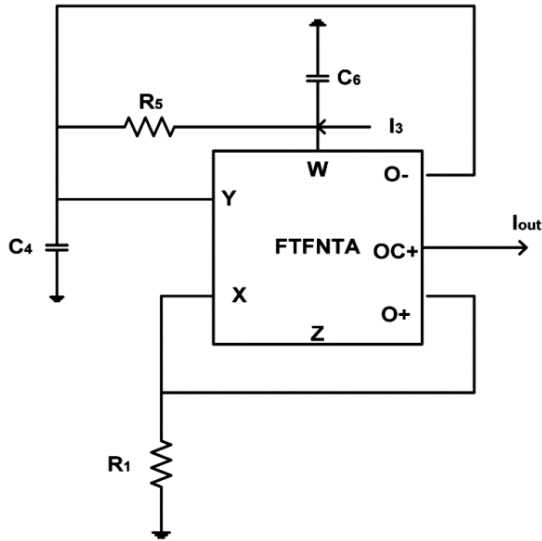


Fig. 4 — Proposed LPF configuration

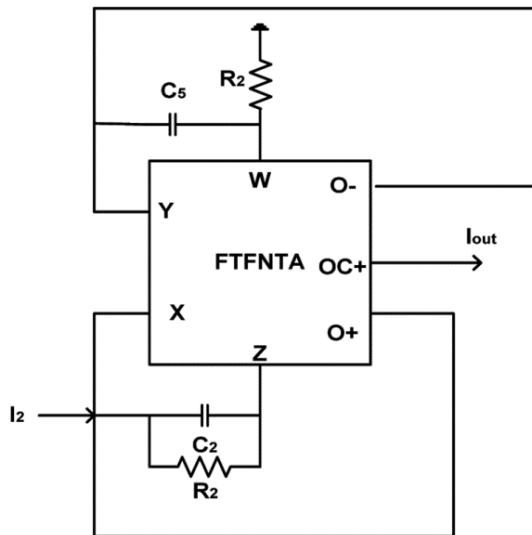


Fig. 5 — Proposed HPF configuration

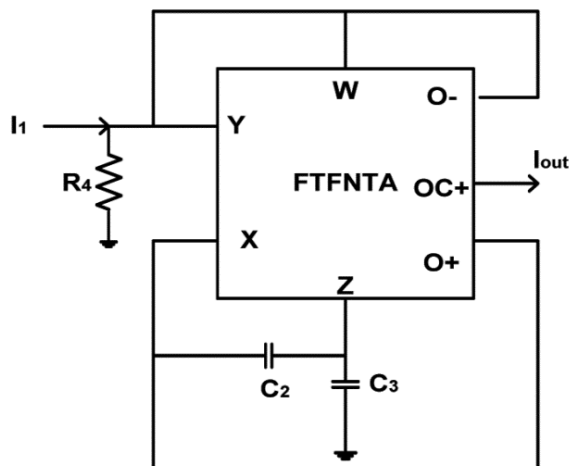


Fig. 6 — Proposed BPF configuration

$Q_0$  and BW of the filter is calculated and mentioned in Table 2.

#### 4 Sensitivities Analysis

Variation of the filter variables,  $\omega_0$  and  $Q_0$  are calculated w.r.to the variation of the active and passive components. So the sensitivity of the proposed filter is derived as follow:

For LPF

$$0 < S_{R_1 R_5 C_4 C_6}^{Q_0} < \frac{1}{2}$$

$$S_{R_1 R_5 C_4 C_6}^{\omega_0} = -\frac{1}{2} \quad \dots(14)$$

For HPF

$$0 < S_{g_m R_2 C_2 C_5}^{Q_0} < \frac{1}{2}$$

$$S_{g_m R_2 C_2 C_5}^{\omega_0} = -\frac{1}{2}$$

$$S_{g_m}^{\omega_0} = \frac{1}{2} \quad \dots(15)$$

For BPF

$$S_{g_m R_4 C_3}^{Q_0} = \frac{1}{2} ;$$

$$S_{C_2}^{Q_0} = -\frac{1}{2} \quad S_{R_4 C_2 C_3}^{\omega_0} = -\frac{1}{2}$$

$$S_{g_m}^{\omega_0} = \frac{1}{2} \quad \dots(16)$$

It is clear from Eqs. (14) - (16) that all the values are lying in the specified range from -1 to 1.

#### 5 Simulation Results

To verify the response of the proposed universal filter PSPICE simulation is performed using CMOS 0.18  $\mu\text{m}$  technology. The simulated frequency response of the designed LPF, HPF, and BPF is demonstrated in Figs 7-9 respectively and it is observed that the

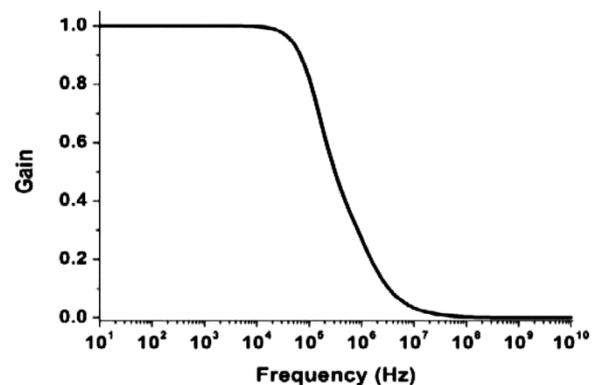


Fig. 7 — Frequency response of LPF

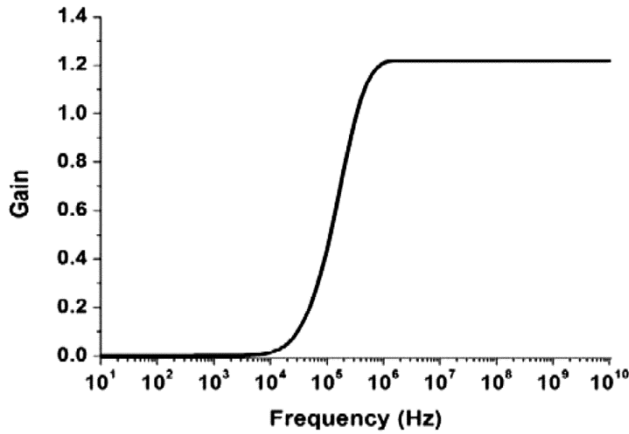


Fig. 8 — Frequency response of HPF

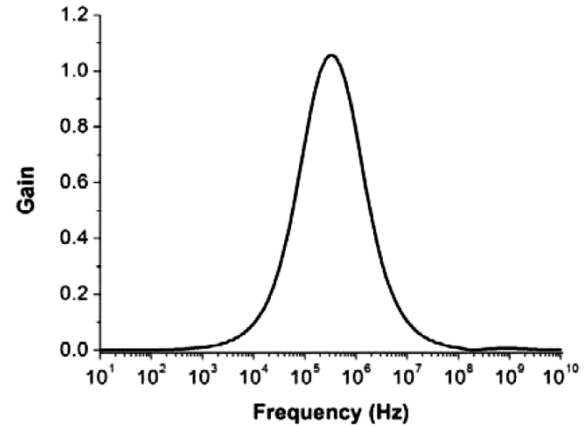


Fig. 9 — Frequency response of BPF

Table 3 — Comparisons of the proposed oscillator with previous reports in references<sup>5-13</sup>

Ref.	Configuration type	Number and type of active element	Number of passive element	Filter type
5	SIMO	1 FTFN	5 (2C+3R)	LP, HP
			5 (3C+2R)	BP
			6 (3C+3R)	BR, AP
6	MISO	1 FTFN+1CFA	5 (2C+3R)	LP, HP, BP,BR,AP
7	MISO	2 FTFN	4(2C+2R)	LP, HP, BP,BR,AP (Current mode)
		2 FTFN	5 (2C+3R)	LP, HP, BP,BR,AP (Voltage mode)
8	SISO	1 FTFN	7 (3C+2R)	LP, HP, BP,BR,AP
9	SISO	1 FTFN	3 (1C+2R)	1 <sup>ST</sup> Order AP
10	MISO	1 FTFN	4(2C+2R)	LP, HP
11	SIMO	3 FTFN	5 (2C+3R)	LP, HP, BP
12	SIMO	3 FTFN	5 (2C+3R)	LP, HP, BP(Current, Voltage and Transimpedance mode)
				HP,BP (Transadmittance mode)
13	SISO	2 FTFN OR 1 FTFN+1 CCII	5 (3C+2R)	BP+HP
			5 (2C+3R)	BP+LP
Proposed	MISO	1FTFN	4 (2C+2R)	LP
			3 (2C+1R)	HP, BP

value of  $f_0$  is 147 kHz for BPF and HPF and 163 kHz for LPF which is approximately equal to the calculated value 139.27kHz for BPF and HPF; and 159.15 kHz for LPF, for  $g_m=697 \mu S$ ,  $R=1k\Omega$  and  $C=1nF$ .

A comparison of the proposed work with existing filters using FTFN is given in Table 3. From the comparison table it is evident that very few filters were designed using single FTFN ABB but requires more passive components.

## 6 Conclusions

A current mode universal biquad filter is designed using single FTFNTA. Sensitivity analysis is also

performed for the proposed structure. A wide comparison is also done with the other FTFN based filters. This work can further be explored for designing of band reject filter and all-pass filter.

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